Assessment of Greenland Turbot in the Eastern Bering Sea and Aleutian Islands

James N. Ianelli, Thomas K. Wilderbuer, and Terrance M. Sample

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center
7600 Sand Point Way NE, Seattle, WA 98115-0070

Summary

Relative to last year's assessment, the following changes have been made in the current assessment.

New input data

1. An updated 1991-2002 fishery catch estimate series
2. The 2003 catch data (assuming a total annual catch of 3,500 t)
3. 2002 and 2003 catch-at-length by gear type
4. EBS shelf survey 2003 biomass and length composition estimates
5. An updated aggregated longline survey data index for the EBS and Aleutian Islands regions

Assessment model

An updated version of the stock synthesis program (January 2003) was used for this year's Greenland turbot assessment. This version has improved diagnostic output and some new features (though these features were not pertinent to this assessment). Otherwise, there were no changes to the assessment model.

Assessment results

The value of $B_{40\%}$ was based on the mean estimated recruitment for the period 1978-1999. Results indicate that the long-term average female spawning biomass is around 58,700 tons. The current estimate of the year 2004 female spawning biomass is about 69,300 t. These values are up slightly from last year's estimates 54,400 for $B_{40\%}$ and 67,800 tons for 2003 spawning biomass. Given the current model structure and general uncertainty about stock structure, we recommend an ABC based on the recent 5-year average fishing mortality **4,740 mt.** We feel that this is justified based on the projections for the anticipated further declines and the continued lack of apparent recruitment. The overfishing level, based on the adjusted $F_{35\%}$ rate is **19,300 t** corresponding to a full-selection F of 0.32.

Introduction

Greenland turbot (*Reinhardtius hippoglossoides*) within the US 200-mile exclusive economic zone are mainly distributed in the eastern Bering Sea (EBS) and Aleutian Islands region. Juveniles are believed to spend the first 3 or 4 years of their lives on the continental shelf and then move to the continental slope (Alton et al. 1988). Juveniles are absent in the Aleutian Islands regions, suggesting that the population in the Aleutians originates from the EBS or elsewhere. In this assessment we assume that the Greenland turbot found in the two regions represent a single management stock. NMFS initiated a tagging study in 1997 to supplement earlier international programs. Results from tag returns suggest that this species is capable of movement over large areas.

Prior to 1985 Greenland turbot and arrowtooth flounder were managed together. Since then, the Council has recognized the need for separate management quotas given large differences in the market value between these species. Furthermore, the abundance trends for these two species are clearly distinct (e.g., Wilderbuer and Sample 1992).

The American Fisheries Society uses “Greenland halibut” as the common name for *Reinhardtius hippoglossoides* instead of Greenland turbot. To avoid confusion with the Pacific halibut, *Hippoglossus stenolepis*, we retain the common name of Greenland turbot which is also the “official” market name in the US and Canada (AFS 1991). For further background on this assessment and the methods used refer to Ianelli and Wilderbuer (1995).

Catch history and fishery data

Catches of Greenland turbot and arrowtooth flounder were not reported separately during the 1960s. During that period, combined catches of the two species ranged from 10,000 to 58,000 t annually and averaged 33,700 t. Beginning in the 1970s the fishery for Greenland turbot intensified with catches of this species reaching a peak from 1972 to 1976 of between 63,000 t and 78,000 t annually (Fig. 5.1). Catches declined after implementation of the MFCMA in 1977, but were still relatively high in 1980-83 with an annual range of 48,000 to 57,000 t (Table 5.1). Since 1983, however, trawl harvests declined steadily to a low of 7,100 t in 1988 before increasing slightly to 8,822 t in 1989 and 9,619 t in 1990. This overall decline is due mainly to catch restrictions placed on the fishery because of declining recruitment. For the period 1992–1997, the Council set the TAC’s to 7,000 t as an added conservation measure due to concerns about apparent low levels of recruitment in the past several years. This has resulted in primarily bycatch-only fisheries. The distribution of the Greenland turbot catches has been fairly consistent in recent years (Figs. 4.2 and 4.3).

Catch information prior to 1990 included only the tonnage of Greenland turbot retained Bering Sea fishing vessels or processed onshore (as reported by PacFIN). Discard levels of Greenland turbot have typically been highest in the sablefish fisheries (at about one half of all sources of Greenland turbot discards during 1992-2002) while Pacific cod fisheries and the Greenland turbot directed fishery also have contributed substantially to the discard levels (Table 5.2).

Catch and catch per unit effort (CPUE)

The catch data were used as presented above for both the longline and trawl fisheries. The early catches included Greenland turbot and arrowtooth flounder together. To separate them, we assumed that the ratio of the two species for the years 1960-64 was the same as the mean ratio caught by USSR vessels from 1965-69.

A CPUE index derived in Alton et al. (1988) for the years 1978-84 for the trawl fishery was used as an index of abundance in the stock synthesis model:

Year	1978	1979	1980	1981	1982	1983	1984
CPUE Index	291	316	449	409	235	195	335

Size and age composition

No age composition information is available from the fisheries or surveys. However, limited survey size-at-age data (useful for estimating growth and growth variability) were available from 1975, 1979-1982. Extensive length frequency compositions have been collected by the NMFS observer program from the period 1980 to 1991. The length composition data from the trawl and longline fishery and the expected values from the assessment model are presented in previous assessments. This information is used in the assessment model and adds to our ability to estimate size-specific selectivity patterns in addition to year-class variability.

Resource Surveys

Abundance estimates for juvenile Greenland turbot on the EBS shelf are provided annually by AFSC trawl surveys. The older juveniles and adults on the slope were assessed every third year from 1979-1991 (also in 1981) during U.S.-Japan cooperative surveys. The slope surveys were conducted by Japanese shore-based (Hokuten) trawlers chartered by the Japan Fisheries Agency until 1985. In 1988, the NOAA R/V Miller Freeman surveyed the resources on the EBS slope region. In this same year, chartered Japanese vessels performed side-by-side trawl experiments with the Miller Freeman for calibration purposes. Due to limited vessel time, the area and number of stations sampled by the Miller Freeman was less than sampled by the Japanese trawlers in most previous years. The Miller Freeman sampled 133 stations over a depth interval of 200-800 m while during earlier slope surveys the Japanese vessels usually sampled 200-300 stations over a depth interval of 200-1,000 m (Table 5.3). We believe that the U.S. and Japanese trawl slope-surveys under-estimate the actual biomass of Greenland turbot when swept-area expansions are made. Thus, we treat these as indices of relative abundance. That is, the species appears to extend beyond the area of the survey and that the ability to tend bottom in the deeper waters may be compromised. The AFSC began a new biennial bottom trawl survey of the upper continental slope of the eastern Bering Sea in 2002. Data from this new survey should improve the sampling effort in Greenland turbot habitat areass

The combined estimates from the shelf and slope indicate a decline in EBS abundance for the 4 years of observations that were available during 1979-1985. After 1985, the slope biomass estimates (and the 1991 Aleutian Islands estimate) are not comparable to previous years due to differences in depths sampled. The interpretation of the CPUE data from these surveys, however, suggests a moderate decline in abundance between 1985 and 1991. The average shelf-survey biomass estimate during the last 9 years (1993-2001) is 29,968 tons with a declining trend during this period.

The following table summarizes the sampling that has occurred for the EBS bottom trawl survey data since 1982:

Year	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**
No. hauls	329	354	355	353	354	342	353	353	352	351	336
No. Lengths	969	951	536	196	195	82	200	183	232	360	440
Year	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
No. hauls	355	355	356	355	356	355	353	352	355	355	356
No. Lengths	400	398	313	297	197	93	207	248	274	322	622

Previously, the eastern Bering Sea Cooperative longline survey was incorporated for use as a relative abundance index. This survey covered a larger portion of the slope and shelf area than the present longline survey. A bootstrap resampling scheme was used to provide confidence bounds on the annual relative abundance estimates. We used the median values of the bootstrap estimates as our relative population index. This index represents numerical abundance whereas the shelf and slope surveys represent biomass indices. We continue to work on methods of incorporating recent domestic longline surveys which, beginning in 1996, have been extended into the Bering Sea and part of the Aleutian Islands (in alternate years). This new sampling area represents a smaller region than in past but shows that about 25% of the population along the slope regions is found within the northeast (NE) and southeast (SE) portions of the Aleutian Islands compared to the abundances along the slope of the EBS:

Relative Population No. (RPN)				Year				
Area	1996	1997	1998	1999	2000	2001	2002	2003
Bering 4		11,729		13,072		16,082		11,965
Bering 3		6,172		6,156		5,005		3,784
Bering 2		27,936		33,848		24,766		24,660
Bering 1		13,491		10,068		4,788		6,206
NE Aleutians	23,133		16,124		12,987		10,942	
SE Aleutians	2,142		1,806		1,201		1,397	
Bering Sea		59,328		63,144		50,641		46,616
Aleutians	25,275		17,930		14,188		12,339	
Combined	104,918	78,156	74,427	83,183	58,896	66,712	51,219	61,409

The combined time series shown above (1996-2002) was used as a relative abundance index (Fig. 5.4). It was computed by taking the average RPN from 1996-2002 for both areas and computing the average proportion. The combined *RPN* in each year (RPN_t^c) was thus computed as:

$$RPN_t^c = I_t^{AI} \frac{RPN_t^{AI}}{p^{AI}} + I_t^{EBS} \frac{RPN_t^{EBS}}{p^{EBS}}$$

where I_t^{AI} and I_t^{EBS} are indicator function (0 or 1) depending on whether a survey occurred in either the Aleutian Islands or EBS, respectively. The average proportions are given here by each area as: p^{AI} and p^{EBS} . Note that each year data are added to this time series, the estimate of the combined index changes (slightly) in all years.

A time series of estimated size composition of the population was available for the shelf and slope trawl surveys and for the longline survey. The slope surveys typically sample more turbot than the shelf trawl surveys; consequently, the number of fish measured in the slope surveys is greater. The time series of length frequencies from the longline survey was presented in Ianelli et al. (1994). The Greenland turbot size composition from the 2002 shelf trawl survey is given in Fig. 5.5 while for the new slope survey the length frequencies are given in Fig. 5.6.

Scientific research catches are reported to fulfill requirements of the Magnuson-Stevens Fisheries Conservation and Management Act. The following table documents annual research catches (1977 - 1998) from NMFS longline and trawl surveys (in tons):

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
NMFS Bottom trawl surveys	62.48	48.36	103.01	123.6	15.14	0.73	175.22	72.84	0.56	18.48
Domestic Longline surveys	NA									
Cooperative Longline surveys	3	3	6	11	9	7	8	7	11	6
Year	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
NMFS Bottom trawl surveys	0.64	0.85	11.37	0.88	1.43	8.51	1.44	1.47	4.64	1.38
Domestic Longline surveys										
Cooperative Longline surveys	16	10	10	22	23	23				

Model Structure

The use of the stock synthesis program (Methot 1990) to model the eastern Bering Sea component of Greenland turbot stock was presented in previous assessments (Ianelli et al. 1994, 1995). Before 1994, stock assessments of Greenland turbot in the eastern Bering Sea and Aleutian Islands have relied in part on stock reduction analysis (SRA) to provide historical trends in the fishery (Wilderbuer and Sample 1992). In the past several years, limited effort on simplifying the Greenland turbot has been undertaken. A functional, two-fishery combined-sexes model was completed. Results from this model produce similar patterns of recruitment and abundances when fit to the same length and survey indices. However, further model specification issues need to be addressed before it can be used extensively. For example, inconsistencies with the data seem to become more obvious. We expect to develop this model further in the coming year as time is available.

As with past years, the length-version of the stock synthesis program (Methot 1990) was used for this assessment (updated to the 2003 version of the computer program). Catch data used in the stock synthesis model were from 1960 to 2003. It was assumed that the stock was at or close to its virgin biomass level at the beginning of the catch data time series.

Model parameters were estimated by maximizing the log likelihood (L) of the predicted observations given the data. Data are classified into different components. For example, age composition from a survey and catch per unit effort (CPUE) from a fishery are different components. The total L is a sum of the likelihoods for each component. The total L may also include a component for a stock-recruitment relationship and penalty functions to help stabilize parameter estimates. The likelihood components may be weighted by an emphasis factor. For Greenland Turbot in the EBS the model included two fisheries, those using longline and trawl gear, and three surveys. Table 5.4 summarizes the extent of the data used in the different likelihood components. All emphasis factors were set to 1.0, effectively relying on proper weights from the assumed (or in most cases, estimated) variances for the data sources.

Annual recruitments are estimated as parameters in the model, they can be thought of as "anomalies" from an underlying stock-recruitment curve. These recruitment anomalies can be due to process and observation errors. Process errors refer to the real differences from the mean stock-recruitment curve caused by natural variation in recruitment success. Observation errors refer to our ability to estimate the true recruitment levels due to sampling problems. In this application, observation error is considered negligible compared to the magnitude of recruitment variability (process error). Consequently, the underlying parameters of the stock-recruit curve play an insignificant role in fitting the model to the data. For further details on the model specifications of the length-version of the stock synthesis program, see Thompson *et al.* (Pacific cod chapter, this volume).

Selectivity Patterns

A dome-shaped size-based selectivity function (Methot 1990) was estimated for each survey and fishery described below. For the trawl fishery, the periods of length frequency data collections from the domestic and foreign fleet did not overlap. Consequently, we treated the foreign and domestic trawl data as from a single fishery and simply let the selectivity pattern be different between the respective periods. Because larger fish have been observed in the recent EBS shelf region trawl surveys, selectivity was also was estimated separately for two periods: 1994-present and 1982-1993.

Parameters estimated independently

Natural mortality, length at age, length-weight relationship

The natural mortality of Greenland turbot was assumed to be 0.18. This estimate was used because it is slightly less than that of other flatfish species with a slightly lower maximum age. Greenland turbot taken by the commercial fishery have been aged as old as 21 years.

Parameters describing length-at-age are estimated within the model. We do assume that the length at age 1 is the same for both sexes and that the variability in length at age 1 has an 8% CV and that the variability in length at age 21 has a CV of 7%. This appears to encompass the observed variability in length-at-age.

As in the previous assessments, size-at-age information from surveys conducted between 1976-82 were used in the model to help estimate the relationship between age and length. The length-weight relationship for Greenland turbot estimated by Ianelli et al. (1993) was:

$$w = 2.69 \times 10^{-6} L^{3.3092} \quad \text{for females}$$

and

$$w = 6.52 \times 10^{-6} L^{3.068} \quad \text{for males}$$

where L = length in mm, and w = weight in grams.

Maturation and fecundity

Maturation and fecundity by size or age is poorly understood for Greenland turbot. Alton *et al.* (1988) present the results from studies of Greenland turbot in different areas in addition to the EBS region. For this analysis, we chose a logistic size-maturity relationship which has 50% of the female population mature at 60 cm; 2% and 98% of the females are assumed to be mature at about 50 and 70 cm respectively. This is based on an approximation from D'yakov's (1982) study.

Parameters estimated conditionally

The key parameters estimated within the model include:

- Annual recruitment estimates from 1960-1998 (1965-1969 aggregated to have a single mean value),
- Selectivity parameters for the 2 fisheries, and 3 surveys,
- Growth parameters: 5 parameters (2 for each sex, one in common),
- Parameter that scales the expected value of recruitment, and
- Effective effort-fishing mortality rates for trawl and longline fisheries (solved by matching predicted catch biomass to the observed catch biomass exactly), 1960-2002.

Model evaluation

Size composition data are not available until 1977 hence we are unable to resolve recruitment strength information during the early period (1960s) with the model. Based on earlier assessments (e.g., Ianelli et al. 1999), setting the individual recruitment estimates from 1960-69 equal to that predicted by an equilibrium stock-recruitment relationship gave a poor fit to the size composition data and a high unfished biomass (>1.8 million mt). When all recruitment deviations were estimated (the full model), a single large deviation resulted in the early part of the time series. This indicated a year class more than an order of magnitude greater than the mean estimated recruitment since 1970. Both the full model and the equilibrium recruitment models were therefore unsatisfactory. To compensate, we pooled recruitment deviation estimates from 1965-69 as in Ianelli et al. (1993).

The assumed slope-survey catchability was fixed as before at 0.75. Unlike last year's assessment, we chose to give the recent slope-survey estimate equal weight since there was no information suggesting that the variance estimate should be considerably *lower* than the other survey or fishery information.

Trends in Abundance

The fits to the abundance indices are given in Fig. 5.7. The assessment model predictions for shelf survey biomass are far below the observed estimates during the early years and subsequently track the survey estimates well. These data are consistent with the conclusion of Alton et al. (1988) that recruitment of juveniles in the EBS has been low since the early 1980s. The reason that the model fits the early period of the shelf trawl survey index poorly is because such high levels of recruitment are inconsistent with observations of numbers of older fish later in the time series. The overall trend for the slope survey estimates is mimicked by the assessment model, but indicates biases based on the fixed Q values used in each model for the slope survey. The general trend of the longline survey index shows increasing numbers while the model predicts declines. The failure to fit the apparent increasing trend from the longline survey data with the model reflects the relatively large standard errors associated with this index. If we increase the model emphasis on the survey longline trend, the fits to the other surveys degrades considerably (Ianelli et al. 1995). The effect of high emphasis on the longline survey (increasing biomass trend) would indicate a much higher level of current spawning biomass.

The biomass of Greenland turbot has roughly doubled during the 1970s from the early 1960s level and is currently about half of the unfished level. The 2002 total beginning of the year biomass (age 1 and older) estimate is about 115,700 (with slope survey Q set to 0.75; Fig. 5.8). In past years, extra caution has been exercised in setting harvest levels of Greenland turbot because of the lack of recruitment success in recent years. For this reason, we selected the conservative assumption to have Q for the slope survey set equal to 0.75 for our ABC recommendations. It should be noted that the slope survey biomass estimates do not include the biomass estimates from the Aleutian Islands, which averages about one fourth to one third of the total population biomass. It is therefore still likely that the biomass estimates from this model configuration are biased towards low values. The historical fishing mortality rates (combined gears) increased over time and was highest in 1981 through 1983 (Table 5.5). A comparison of this year's model result with a similar model from the 2002 assessment (except for the added emphasis on fitting the slope survey data in 2002) is also presented in Table 5.5. The estimated historical numbers at age is given in Table 5.6.

Selectivity

Selectivity of Greenland turbot varied considerably between all of the surveys and fisheries. The shelf survey selected only small fish whereas the slope survey caught much larger fish. A similar pattern was observed between the trawl and longline fisheries with the longline fishery consistently catching larger Greenland turbot (Fig. 5.9). Note that the average selectivity estimates for the slope and shelf surveys indicate that our surveys do not sample intermediate size fish (35-50cm) very well. The reason for this is not clear; however, we feel that it is related to the apparent bi-modality in the size distribution observed in the trawl fishery.

Fit to Size Composition Data

Size composition observations from the fisheries and surveys are generally poorly matched by the model predictions. In some years, relatively few fish were measured so adjustments of the model to those data would depend on the trade-off in fitting other data, which may have had more extensive sampling. Second, unaccounted fish movement and hence changing availability affects fits to size composition data when an "average" gear selectivity is used. Finally, natural mortality rate is undoubtedly variable among cohorts and years, the extent of which would affect our ability to model the age structure of the population accurately. The nature of the inconsistencies among data types is presented below, particularly as they pertain to assessing the current stock status.

Recruitment

Recruitment of young juvenile Greenland turbot has been poor since the early 1980s based on EBS shelf trawl surveys. There were several strong year-classes through the 1970s, which were followed by poor recruitment of Greenland turbot since the early 1980s (Fig. 5.10). Preliminary analyses on fitting the stock-recruitment relationship indicated that the residuals were highly auto-correlated. For the present analyses, the authors feel that model assumptions are too great to pursue stock-recruitment analyses. Progress was made in the past year towards developing alternative model for Greenland turbot. This new approach may prove useful for providing reasonable estimates of F_{msy} (and associated uncertainty) that may be useful in considerations for Tier 1 of Amendment 56.

Projections and harvest alternatives

Maximum Sustainable Yield

Maximum sustainable yield (MSY) calculations require assumptions about the stock recruitment relationship, which for Greenland turbot may be impractical as many functional forms can fit the data equally well. As presented above, the harvest strategy relative to reductions in spawning biomass per recruit (e.g., $F_{40\%}$) was selected in the absence of information on the stock-recruitment productivity relationship required for calculating MSY levels.

ABC and Overfishing levels

The recommended harvest levels vary considerably among models depending on the assumptions made about the catchability coefficients from the slope-trawl survey (Ianelli et al. 1999). Since there are several areas of uncertainty surrounding this assessment, for the basis for recommendations we selected a conservative configuration (assuming slope-survey catchability=0.75). The status of the projected spawning biomass in year 2003 relative to $B_{40\%}$ would place Greenland turbot in Tier 3a of Amendment 56.

We computed $B_{40\%}$ value by using the mean recruitment estimated for the period 1978-1998. The results indicate that the long-term average female spawning biomass is around 58,800 tons. The current estimate of the year 2003 female spawning biomass is about 73,500 t.

While the Council and past recommendations have intentionally been extra conservative with the idea of promoting the recovery of Greenland turbot in the EBS and Aleutian Islands region, the stock appears to be on a continuing decline. While the stock is technically not overfished and is currently above $B_{40\%}$, we feel that extra caution is warranted. The new survey information from the slope region provides insight on the abundance of Greenland turbot in their main habitat area (the most recent survey prior to that of 2002 was in 1991). However, we feel that an ABC based on the recent 5-year average fishing mortality is recommended which is **4,740 tons.** We feel that this is justified since in the projections we anticipate further declines given the current estimate of the age composition of the stock.

Our recommendation for overfishing, based on the adjusted $F_{35\%}$ rate is **17,800 t** corresponding to a full-selection F of 0.32. The value of the Council's overfishing definition depends on the age-specific selectivity of the fishing gear, the somatic growth rate, natural mortality, and the size (or age) -specific maturation rate. As this rate depends on assumed selectivity, future yields are sensitive to relative gear-specific harvest levels. Because harvest of this resource is not allocated by gear type, the unpredictable nature of future harvests between gears is an added source of uncertainty. However, this uncertainty is considerably less than uncertainty related to treatment of survey biomass levels, i.e., factors which contribute to estimating absolute biomass (Ianelli et al. 1999).

Standard harvest scenarios and projections

This year, a standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2003 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2004 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2003 (here assumed to be 3,500 t). In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1,000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2004, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, *F* is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the 0.75.
Scenario 3: In all future years, *F* is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)
Scenario 4: In all future years, *F* is set equal to the 1999-2003 average *F*. (Rationale: For some stocks, TAC can be well below ABC, and recent average *F* may provide a better indicator of F_{TAC} than F_{ABC}.)
Scenario 5: In all future years, *F* is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)
Scenarios 1 through 5 were projected 13 years from 2003 (Table 5.7).

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, *F* is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above ½ of its MSY level in 2004 and above its MSY level in 2014 under this scenario, then the stock is not overfished.)
Scenario 7: In 2004 and 2005, *F* is set equal to *max* F_{ABC}, and in all subsequent years, *F* is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2016 under this scenario, then the stock is not approaching an overfished condition.)
Our projection model run under these conditions indicates that for Scenario 6, the Greenland turbot stock is not overfished based on the first criterion (year 2004 spawning biomass estimated at 69,300 t relative to ½ $B_{35\%}$ = 25,700 tons). Under the guidelines, since the year 2004 biomass estimate is well above the $B_{35\%}$ level (and $B_{40\%}$) we have determined that the stock is not overfished.

Projections of fishable biomass 13 years into the future under alternative fishing mortality rates were examined. The same natural mortality and growth parameters that were used in the previous stock synthesis runs were employed for the projections. The results fishing at the maximum permissible and at the 5-year average *F* both suggest a continued decline in spawning biomass until about 2009 (Fig. 5.11). However, fishing at the 5-year average *F* is more likely to keep the stock size above the $B_{35\%}$ level (the expectation is that it will drop to 57,600 t compared to the $B_{35\%}$ level of 51,400). Projections with fishing at the maximum permissible results in an expected value of spawning biomass of 41,000 t in 2009.

Under Scenarios 6 and 7, the projected spawning biomass for Greenland turbot is not currently overfished, nor is it approaching an overfished status.

Other Considerations

Subarea Allocation

In this assessment, we have adopted the hypothesis proposed by Alton et al. (1989) regarding the stock structure of Greenland turbot in the eastern Bering Sea and Aleutian Islands regions. Briefly, spawning is thought to occur throughout the adult range with post-larval settlement occurring on the shelf in shallow areas. The young fish on the shelf begin to migrate to the slope region at about age 4 or 5. In our treatment, the spawning stock includes adults in the Aleutian Islands and the eastern Bering Sea. In support of this hypothesis, we examined the length compositions from the Aleutian Islands surveys and found a lack of small Greenland turbot, which suggests that these fish migrate from other areas (Ianelli et al. 1993). Historically, the catches between the Aleutian Islands and eastern Bering Sea has varied (Table 5.8).

Since we acknowledge having limited information on the movement and recruitment processes for this species and in the interest of harvesting the “stock” evenly, we recommend that the ABC be split between regions. Based on eastern Bering Sea slope survey estimates and Aleutian Islands surveys, the proportion of the adult biomass in the Aleutian Islands region has ranged from 24% to 49%. We therefore recommend the ABC for the Aleutian Islands be set 33% of the total ABC, with 67% allocated to the eastern Bering Sea. These rates represent the mid-point of the values observed from biomass estimates and give the following allocation:

Aleutian Islands	1,578 mt
Eastern Bering Sea	3,162 mt
Total	4,740 mt

Ecosystem considerations

Greenland turbot have undergone dramatic declines in the abundance of immature fish on the EBS shelf region compared to observations during the late 1970’s. It may be that the high level of abundance during this period was unusual and the current level is typical for Greenland turbot life history pattern. Without further information on where different life-stages are currently residing, we can only speculate on the plausibility of this scenario. Several major predators on the shelf were at relatively low stock sizes during the late 1970’s (e.g., Pacific cod, Pacific halibut) and these increased to peak levels during the mid 1980’s. Perhaps this shift in abundance has reduced the survival of juvenile Greenland turbot in the EBS shelf. Alternatively, the shift in recruitment patterns for Greenland turbot may be due to the documented environmental regime that occurred during the late 1970’s. That is, perhaps the critical life history stages are subject to different oceanographic conditions that affect the abundance of juvenile Greenland turbot on the EBS shelf.

Currently, the ecosystem group within the REFM Division is actively evaluating the pattern of mortality between different species in the EBS. One aspect of this work involves developing a multi-species model. Results from this work indicate that Greenland turbot is an important predator.

A tagging study of Greenland turbot conducted by the NMFS Auke Bay Lab staff is continuing. This year scientist aboard the longline survey tagged and released 100 Greenland turbot bringing the total number of releases up to 841. Last year we reported on a Greenland turbot that was at large for over 16 years and recaptured on the Bering Sea slope area. This individual fish was tagged in the Sea of Okhotsk, suggesting that Greenland turbot in the EBS/AI may not be a closed population. In addition, the Auke Bay lab scientists tagged 45 Greenland turbot with electronic (archival) tags in the Bering Sea this year. These tags will hopefully help understand more about the movement patterns of these fish around the Bering Sea and Aleutian Islands.

Summary

The management parameters of interest derived from this assessment are presented in Table 5.9.

Acknowledgments

We thank Chris Lunsford for providing the 2003 longline survey data summaries and Nancy Maloney for continuing to process Greenland turbot tag release and recapture data.

References

AFS Publication, 1991. Common and Scientific Names of Fishes from the United States and Canada. American Fisheries Society Special Publication 20. C. Richard Robins, Chairman. 183 p. American Fisheries Society, 5410 Grosvenor Lane, Suite 110, Bethesda, MD 20814-2199.

Alton, M.S., R.G. Bakkala, G.E. Walters, and P.T. Munro. 1988. Greenland turbot *Reinhardtius hippoglossoides* of the eastern Bering Sea and Aleutian Islands region. NOAA Tech. Rep., NMFS 71, 31 p.

Beverton, R.J.H. and S.J. Holt. 1957. On the dynamics of exploited fish populations. Fish. Invest., Lond., Ser. 2, 19.

D'yakov, Yu. P. 1982. The fecundity of the Greenland turbot, *Reinhardtius hippoglossoides*, (Pleuronectidae), from the Bering Sea. J. Ichthyol. [Engl. Transl. Vopr. Ikhtiol] 22(5):59-64.

Harrison, R.C. 1993. Data Report: 1991 Bottom trawl survey of the Aleutian Islands Area. NOAA Tech. Memo. NMFS-AFSC-12. 144p.

Ianelli, J.N., T.K. Wilderbuer, and T.M. Sample. 1993. Stock assessment of Greenland turbot. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 1994. Section 4. North Pacific Fishery Management Council, Anchorage, AK.

Ianelli, J.N., T.K. Wilderbuer, and T.M. Sample. 1994. Stock assessment of Greenland turbot. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 1995. Section 4. North Pacific Fishery Management Council, Anchorage, AK.

Ianelli, J.N. and T. K. Wilderbuer. 1995. Greenland Turbot (*Reinhardtius hippoglossoides)* stock assessment and management in the Eastern Bering Sea. *In:* Proceedings of the International Symposium on North Pacific Flatfish. Alaska Sea Grant. AK-SG-95-04:407-441.

Ianelli, J.N., T.K. Wilderbuer, and T.M. Sample. 1999. Stock assessment of Greenland turbot. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 2000. Section 4. North Pacific Fishery Management Council, Anchorage, AK.

Kimura, D.K. 1988. Analyzing relative abundance indices with log-linear models. N. Am. Journ. Fish. Manage. 8:175-180.

Methot, R.D. 1990. Synthesis model: an adaptable framework for analysis of diverse stock assessment data. *In* Proceedings of the symposium on applications of stock assessment techniques to Gadids. L. Low [ed.]. Int. North Pac. Fish. Comm. Bull. 50: 259-277.

Wilderbuer, T.K. and T.M. Sample. 1992. Stock assessment of Greenland turbot. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 1993. Section 4. North Pacific Fishery Management Council, Anchorage, AK.

Zenger, H.H. and M.F. Sigler. 1992. Relative abundance of Gulf of Alaska sablefish and other groundfish based on NMFS longline surveys, 1988-90. U.S. Dept. of Comm. NOAA Tech. Memo. NMFS F/NWC-216.

Tables

Table 5.1. Catches of Greenland turbot by gear type (including discards) since implementation of the MFCMA.

Year	Trawl	Longline & Pot	Total
1977	29,722	439	30,161
1978	39,560	2,629	42,189
1979	38,401	3,008	41,409
1980	48,689	3,863	52,552
1981	53,298	4,023	57,321
1982	52,090	32	52,122
1983	47,529	29	47,558
1984	23,107	13	23,120
1985	14,690	41	14,731
1986	9,864	0	9,864
1987	9,551	34	9,585
1988	6,827	281	7,108
1989	8,293	529	8,822
1990	10,869	577	11,446
1991	6,245	1,617	7,863
1992	749	3,003	3,752
1993	1,145	7,323	8,467
1994	6,426	3,845	10,272
1995	3,978	4,215	8,194
1996	1,653	4,902	6,555
1997	1,209	5,989	7,199
1998	1,830	7,319	9,149
1999	1,799	4,057	5,857
2000	1,946	5,027	6,973
2001	2,149	3,163	5,312
2002	1,033	2,605	3,638
2003*	971	2,451	3,422

* Estimate as of 10/14/02, source: NMFS Regional Office, Juneau, AK

Table 5.2. Estimates of discarded and retained (mt) Greenland turbot based on NMFS Blend estimates by directed fishery, 1992-2002.

	Greenland turbot		**Sablefish**		**Pacific cod**		**Rockfish**		**Flatfish**		**Others**		**Combined**	
Year	Retained	Discarded	Retained	Discarded	Retained	Discarded	Retained	Discarded	Retained	Discarded	Retained	Discarded	Retained	Discarded
1992	62	13	196	2,121	135	557	180	103	13	3	107	261	694	3,058
1993	5,685	332	235	880	160	108	572	87	19	185	10	194	6,681	1,786
1994	6,316	368	194	2,305	149	211	316	37	27	235	38	76	7,040	3,232
1995	5,093	327	157	1,546	145	284	362	25	5	102	28	121	5,789	2,405
1996	3,451	173	200	1,026	170	307	598	113	171	63	143	140	4,733	1,822
1997	4,709	521	129	619	270	283	202	19	212	92	18	125	5,539	1,659
1998	6,905	301	125	171	278	154	42	2	628	249	123	171	8,101	1,048
1999	4,009	227	179	120	180	50	25	2	600	269	134	61	5,128	729
2000	4,798	177	192	253	130	108	39	1	838	176	186	75	6,183	790
2001	2,727	89	171	325	203	92	431	30	764	337	95	47	4,391	921
2002	1,979	73	144	207	210	139	175	18	301	217	124	49	2,934	703

Table 5.3. Survey estimates of Greenland turbot biomass for the Eastern Bering Sea shelf and slope areas and for the Aleutian Islands region, 1975-2003.

	Eastern Bering Sea			Aleutians
Year	**Shelf**	**Slope**	**Shelf and Slope Combined**	
1975	126,700	---	---	---
1979	225,600	123,000	348,600	---
1980	172,200	---	---	48,700
1981	86,800	99,600	186,400	---
1982	48,600	90,600	139,200	---
1983	35,100	---	---	63,800
1984	17,900	---	---	---
1985	7,700	79,200	86,900	---
1986	5,600	---	---	76,500
1987	10,600	---	---	---
1988	14,800	42,700*	57,500*	---
1989	8,900	---	---	---
1990	14,300	---	---	---
1991	13,000	40,500	53,900*	11,925**
1992	24,000	---	---	---
1993	30,400	---	---	---
1994	48,800	---	---	28,227**
1995	34,800	---	---	---
1996	30,300	---	---	---
1997	29,218	---	---	28,334**
1998	28,126	---	---	---
1999	19,797	---	---	---
2000	22,957	---	---	9,359**
2001	25,311	---	---	---
2002	21,616	27,589	49,205	9,891**
2003	24,093			

* The 1988 and 1991 estimate are from 200-800 m whereas earlier (and 2000) slope estimates are from 200-1,000 m.

** The 1980, 1983, and 1986 surveys sampled 1-900 m whereas the 1991 - 2002 surveys sampled only 1-500 m.

*** Based on a preparatory survey using mudsweep footrope. These data were not used in the assessment model. See text for further details.

Table 5.4. Data sets used in the stock synthesis model for Greenland Turbot in the EBS. All size and age data are specified by sex.

Data Component	**Years of data**
Survey Size at age data	1975, 1979-82
Shelf Survey: size composition and biomass estimates	1979-2003
Slope Survey: size composition and biomass estimates	1979, 81, 82, 85, 88, 91, 2002
Longline Survey: size composition and abundance index	1996-2003
Total Fishery Catch Data	1960-2003
Trawl CPUE Index	1978-1984
Trawl Catch Size Composition	1977-87, 1989-91, 1993-2003
Longline Catch Size Composition	1977, 1979-85, 1992-2003

Table 5.5. Total fishing mortality rate, spawning and total biomass (compared with the past assessment) for BSAI Greenland turbot, 1960-2003.

		Female Spawning Biomass		Total Age 1+ Biomass	
Year	**F**	**2002 Assessment**	**Current Assessment**	**2002 Assessment**	**Current Assessment**
1960	0.060	294,820	294,504	494,540	493,624
1961	0.099	278,054	277,664	468,494	467,843
1962	0.110	251,564	251,076	428,177	428,358
1963	0.066	225,101	224,565	389,004	390,631
1964	0.074	212,058	211,671	371,808	375,342
1965	0.023	198,890	199,061	359,664	364,865
1966	0.029	198,051	199,388	372,608	378,470
1967	0.052	196,918	199,976	401,401	406,943
1968	0.070	192,004	196,826	443,197	447,537
1969	0.063	185,586	191,725	496,649	499,012
1970	0.040	188,753	195,839	560,140	560,917
1971	0.072	214,766	222,379	636,175	635,826
1972	0.119	251,026	257,741	679,346	679,975
1973	0.099	279,974	284,360	667,408	669,661
1974	0.125	311,828	313,967	649,628	653,149
1975	0.118	323,166	324,025	602,233	606,854
1976	0.119	317,603	319,129	560,467	563,380
1977	0.065	295,085	298,155	519,583	521,549
1978	0.100	283,517	287,472	511,518	515,321
1979	0.103	264,370	267,019	491,966	496,681
1980	0.136	249,162	249,755	474,171	482,272
1981	0.155	228,826	230,017	444,774	455,790
1982	0.131	207,582	211,278	406,880	420,415
1983	0.130	192,250	198,441	367,897	383,374
1984	0.070	179,610	188,365	326,858	343,549
1985	0.048	178,994	189,119	305,180	322,224
1986	0.034	178,901	189,515	288,286	305,247
1987	0.036	176,229	187,061	274,537	291,055
1988	0.029	168,397	179,074	261,251	277,864
1989	0.045	158,686	168,763	250,816	268,055
1990	0.069	146,137	155,663	238,774	257,098
1991	0.052	133,056	142,476	223,514	242,783
1992	0.037	123,694	137,271	209,081	233,389
1993	0.090	122,378	136,751	204,093	228,686
1994	0.085	116,400	131,344	194,472	219,096
1995	0.080	108,638	123,712	182,215	206,690
1996	0.078	102,819	117,808	171,534	195,313
1997	0.093	98,908	114,000	161,805	184,488
1998	0.121	93,805	109,027	151,092	172,635
1999	0.078	86,238	100,848	139,131	158,975
2000	0.099	80,313	94,035	130,747	148,814
2001	0.075	73,144	85,771	121,948	138,098
2002	0.075	67,759	79,234	115,685	129,948
2003	0.059		74,461		124,558

Table 5.6. Estimated beginning of year numbers of Greenland turbot by age and sex (millions).

Females

Yr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
1974	25.67	17.92	12.27	8.69	12.39	22.16	17.00	13.39	10.55	8.26	1.76	1.39	1.11	0.89	0.72	0.51	0.39	0.30	0.25	0.21	1.02
1975	27.24	21.35	14.89	10.02	6.64	9.14	16.22	12.43	9.79	7.71	6.04	1.29	1.02	0.81	0.65	0.53	0.38	0.29	0.22	0.18	0.90
1976	33.12	22.66	17.75	12.18	7.70	4.93	6.74	11.96	9.16	7.22	5.68	4.45	0.95	0.75	0.60	0.48	0.39	0.28	0.21	0.16	0.80
1977	22.91	27.54	18.84	14.51	9.35	5.71	3.64	4.96	8.81	6.75	5.31	4.18	3.28	0.70	0.55	0.44	0.35	0.29	0.20	0.15	0.71
1978	40.24	19.10	22.95	15.56	11.62	7.36	4.48	2.85	3.89	6.90	5.28	4.16	3.28	2.56	0.55	0.43	0.35	0.28	0.22	0.16	0.67
1979	19.67	33.51	15.90	18.89	12.26	8.94	5.64	3.43	2.18	2.97	5.25	4.02	3.16	2.48	1.94	0.41	0.33	0.26	0.21	0.17	0.63
1980	15.01	16.38	27.90	13.08	14.88	9.43	6.85	4.31	2.62	1.66	2.26	3.99	3.04	2.39	1.87	1.46	0.31	0.25	0.20	0.16	0.60
1981	9.92	12.49	13.62	22.85	10.11	11.14	7.02	5.09	3.20	1.94	1.23	1.66	2.92	2.22	1.74	1.36	1.06	0.23	0.18	0.14	0.55
1982	4.79	8.25	10.38	11.13	17.46	7.45	8.15	5.12	3.70	2.32	1.40	0.88	1.19	2.09	1.59	1.24	0.97	0.76	0.16	0.13	0.49
1983	3.20	3.98	6.85	8.47	8.47	12.79	5.42	5.92	3.72	2.69	1.69	1.02	0.64	0.87	1.52	1.15	0.90	0.70	0.55	0.12	0.45
1984	4.61	2.66	3.31	5.59	6.45	6.21	9.31	3.94	4.30	2.70	1.95	1.23	0.74	0.47	0.63	1.10	0.84	0.65	0.51	0.40	0.41
1985	9.32	3.84	2.21	2.73	4.45	5.03	4.82	7.23	3.06	3.34	2.10	1.52	0.95	0.57	0.36	0.49	0.86	0.65	0.51	0.40	0.63
1986	14.96	7.77	3.20	1.83	2.21	3.55	4.00	3.84	5.75	2.43	2.66	1.67	1.21	0.76	0.46	0.29	0.39	0.68	0.52	0.40	0.81
1987	9.53	12.48	6.48	2.66	1.50	1.78	2.86	3.23	3.10	4.64	1.96	2.14	1.35	0.97	0.61	0.37	0.23	0.31	0.55	0.42	0.98
1988	6.10	7.95	10.41	5.38	2.17	1.21	1.44	2.31	2.60	2.49	3.74	1.58	1.73	1.09	0.78	0.49	0.30	0.19	0.25	0.44	1.13
1989	5.18	5.09	6.64	8.65	4.41	1.76	0.98	1.17	1.88	2.11	2.03	3.03	1.28	1.40	0.88	0.64	0.40	0.24	0.15	0.21	1.27
1990	7.27	4.33	4.25	5.54	7.23	3.68	1.46	0.80	0.94	1.51	1.69	1.62	2.43	1.03	1.12	0.70	0.51	0.32	0.19	0.12	1.18
1991	10.36	6.07	3.61	3.55	4.63	6.03	3.04	1.18	0.63	0.74	1.18	1.32	1.27	1.89	0.80	0.87	0.55	0.40	0.25	0.15	1.01
1992	4.31	8.65	5.07	3.02	2.97	3.86	5.00	2.48	0.95	0.51	0.59	0.94	1.06	1.01	1.51	0.64	0.69	0.44	0.31	0.20	0.92
1993	3.23	3.60	7.23	4.23	2.52	2.48	3.22	4.16	2.06	0.79	0.42	0.49	0.77	0.86	0.82	1.22	0.52	0.56	0.35	0.25	0.90
1994	2.86	2.70	3.01	6.04	3.54	2.10	2.06	2.67	3.43	1.68	0.64	0.34	0.39	0.61	0.68	0.64	0.95	0.40	0.43	0.27	0.89
1995	2.81	2.39	2.26	2.51	5.04	2.95	1.74	1.68	2.15	2.73	1.33	0.50	0.26	0.30	0.47	0.52	0.50	0.73	0.31	0.33	0.89
1996	4.00	2.34	2.00	1.88	2.10	4.21	2.45	1.43	1.37	1.74	2.19	1.06	0.40	0.21	0.24	0.37	0.41	0.39	0.57	0.24	0.95
1997	3.49	3.34	1.96	1.67	1.57	1.75	3.50	2.03	1.18	1.12	1.41	1.76	0.85	0.32	0.16	0.19	0.29	0.32	0.30	0.44	0.92
1998	3.44	2.92	2.79	1.63	1.39	1.31	1.46	2.90	1.67	0.96	0.90	1.13	1.40	0.67	0.25	0.13	0.14	0.22	0.25	0.23	1.04
1999	3.25	2.87	2.44	2.33	1.37	1.16	1.09	1.20	2.37	1.35	0.77	0.71	0.88	1.08	0.51	0.19	0.10	0.11	0.17	0.18	0.95
2000	4.81	2.71	2.40	2.03	1.94	1.14	0.97	0.90	0.99	1.93	1.09	0.62	0.57	0.70	0.85	0.40	0.15	0.08	0.09	0.13	0.88
2001	4.81	4.02	2.26	2.00	1.70	1.62	0.95	0.80	0.74	0.80	1.55	0.87	0.49	0.44	0.54	0.66	0.31	0.11	0.06	0.06	0.76
2002	4.81	4.02	3.36	1.89	1.67	1.42	1.35	0.78	0.65	0.60	0.65	1.24	0.69	0.38	0.35	0.42	0.51	0.24	0.09	0.05	0.64
2003	4.81	4.02	3.36	2.80	1.58	1.40	1.18	1.12	0.64	0.54	0.49	0.52	1.00	0.55	0.31	0.28	0.34	0.41	0.19	0.07	0.54

Males

Yr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
1974	25.67	17.92	12.27	8.70	12.50	22.48	17.22	13.52	10.64	8.34	1.78	1.40	1.12	0.90	0.74	0.53	0.40	0.32	0.26	0.21	1.10
1975	27.24	21.35	14.89	10.04	6.71	9.27	16.49	12.60	9.89	7.78	6.10	1.30	1.03	0.82	0.67	0.54	0.39	0.30	0.23	0.19	0.97
1976	33.12	22.66	17.75	12.20	7.78	5.01	6.86	12.17	9.29	7.29	5.74	4.50	0.96	0.76	0.61	0.49	0.40	0.29	0.22	0.17	0.87
1977	22.91	27.54	18.84	14.53	9.45	5.81	3.70	5.05	8.96	6.84	5.37	4.23	3.32	0.71	0.56	0.45	0.37	0.30	0.22	0.17	0.78
1978	40.24	19.10	22.95	15.57	11.68	7.46	4.56	2.90	3.96	7.02	5.36	4.21	3.32	2.61	0.56	0.44	0.35	0.29	0.24	0.17	0.74
1979	19.67	33.51	15.90	18.91	12.34	9.03	5.72	3.49	2.22	3.03	5.37	4.10	3.22	2.54	1.99	0.43	0.34	0.27	0.22	0.18	0.70
1980	15.01	16.38	27.89	13.09	14.98	9.53	6.92	4.38	2.67	1.70	2.32	4.10	3.13	2.46	1.94	1.53	0.33	0.26	0.21	0.17	0.68
1981	9.92	12.49	13.62	22.88	10.20	11.28	7.11	5.15	3.25	1.98	1.26	1.72	3.04	2.33	1.83	1.44	1.14	0.24	0.19	0.16	0.63
1982	4.79	8.25	10.38	11.14	17.64	7.56	8.27	5.20	3.76	2.37	1.45	0.92	1.25	2.22	1.70	1.33	1.05	0.83	0.18	0.14	0.58
1983	3.20	3.98	6.85	8.48	8.56	13.00	5.51	6.01	3.77	2.73	1.72	1.05	0.67	0.91	1.62	1.24	0.98	0.77	0.61	0.13	0.53
1984	4.61	2.66	3.31	5.60	6.52	6.32	9.49	4.01	4.37	2.74	1.99	1.25	0.77	0.49	0.67	1.19	0.91	0.72	0.57	0.45	0.49
1985	9.32	3.84	2.21	2.73	4.48	5.10	4.92	7.37	3.11	3.39	2.13	1.54	0.98	0.60	0.38	0.52	0.93	0.71	0.56	0.44	0.73
1986	14.96	7.77	3.20	1.83	2.22	3.58	4.06	3.91	5.86	2.48	2.70	1.70	1.23	0.78	0.47	0.30	0.41	0.74	0.57	0.45	0.94
1987	9.53	12.48	6.48	2.66	1.50	1.79	2.89	3.28	3.16	4.73	2.00	2.18	1.37	0.99	0.63	0.38	0.25	0.34	0.60	0.46	1.12
1988	6.10	7.95	10.41	5.38	2.17	1.21	1.45	2.33	2.64	2.54	3.81	1.61	1.76	1.10	0.80	0.51	0.31	0.20	0.27	0.48	1.28
1989	5.18	5.09	6.64	8.66	4.42	1.77	0.99	1.18	1.89	2.15	2.07	3.10	1.31	1.43	0.90	0.65	0.41	0.25	0.16	0.22	1.43
1990	7.27	4.33	4.25	5.54	7.23	3.69	1.48	0.82	0.96	1.54	1.74	1.67	2.49	1.05	1.15	0.72	0.52	0.33	0.20	0.13	1.33
1991	10.36	6.07	3.61	3.55	4.63	6.03	3.07	1.21	0.66	0.77	1.22	1.37	1.31	1.96	0.83	0.90	0.57	0.41	0.26	0.16	1.15
1992	4.31	8.65	5.07	3.02	2.97	3.86	5.03	2.54	1.00	0.54	0.63	0.99	1.11	1.06	1.58	0.67	0.73	0.46	0.33	0.21	1.05
1993	3.23	3.60	7.23	4.23	2.52	2.48	3.23	4.19	2.12	0.83	0.45	0.52	0.82	0.92	0.87	1.31	0.55	0.60	0.38	0.27	1.04
1994	2.86	2.70	3.01	6.04	3.54	2.11	2.07	2.69	3.48	1.75	0.68	0.37	0.43	0.67	0.75	0.71	1.06	0.45	0.49	0.31	1.06
1995	2.81	2.39	2.26	2.51	5.04	2.95	1.75	1.71	2.20	2.83	1.41	0.55	0.30	0.34	0.53	0.60	0.57	0.85	0.36	0.39	1.08
1996	4.00	2.34	2.00	1.88	2.10	4.21	2.46	1.45	1.41	1.80	2.30	1.15	0.44	0.24	0.27	0.43	0.48	0.46	0.68	0.29	1.18
1997	3.49	3.34	1.96	1.67	1.57	1.75	3.51	2.05	1.21	1.16	1.48	1.89	0.94	0.36	0.19	0.22	0.35	0.39	0.37	0.55	1.19
1998	3.44	2.92	2.79	1.63	1.39	1.31	1.46	2.92	1.70	1.00	0.96	1.22	1.55	0.77	0.30	0.16	0.18	0.28	0.32	0.30	1.40
1999	3.25	2.87	2.44	2.33	1.37	1.16	1.10	1.21	2.42	1.40	0.82	0.78	0.99	1.26	0.62	0.24	0.13	0.15	0.23	0.25	1.36
2000	4.81	2.71	2.40	2.03	1.94	1.14	0.97	0.91	1.01	1.99	1.15	0.67	0.64	0.81	1.02	0.50	0.19	0.10	0.12	0.18	1.30
2001	4.81	4.02	2.26	2.00	1.70	1.62	0.95	0.81	0.75	0.83	1.63	0.94	0.54	0.52	0.65	0.83	0.41	0.16	0.08	0.10	1.19
2002	4.81	4.02	3.36	1.89	1.67	1.42	1.35	0.79	0.67	0.62	0.68	1.33	0.76	0.44	0.42	0.53	0.67	0.33	0.13	0.07	1.03
2003	4.81	4.02	3.36	2.80	1.58	1.40	1.18	1.13	0.66	0.55	0.51	0.56	1.10	0.63	0.36	0.34	0.43	0.55	0.27	0.10	0.90

Table 5.7. Mean spawning biomass, F, and yield projections for Greenland turbot, 2003-2016. The full-selection fishing mortality rates (*F's*) between longline and trawl gears were assumed **equal**. The values for $B_{40\%}$ and $B_{35\%}$ are 58,800 and 51,400 tons, respectively.

Female sp. Biomass	Max F_{ABC}	75% Max F_{ABC}	Half max F_{ABC}	5-year avg.	No Fishing	Scenario 6	Scenario 7
2003	73,509	73,509	73,509	73,509	73,509	73,509	73,509
2004	69,274	69,274	69,274	69,274	69,274	69,274	69,274
2005	56,339	59,084	61,977	64,614	68,243	53,850	56,339
2006	47,802	51,777	56,600	61,211	67,892	44,534	47,802
2007	43,385	47,645	53,096	58,958	68,165	40,062	41,969
2008	41,301	45,542	51,194	57,679	68,981	38,109	39,246
2009	40,993	45,125	50,801	57,579	70,644	37,956	38,624
2010	42,695	46,731	52,392	59,356	73,954	39,769	40,145
2011	45,867	49,911	55,652	62,913	78,945	42,950	43,144
2012	49,345	53,569	59,594	67,347	84,772	46,294	46,379
2013	52,484	57,085	63,635	72,080	90,974	49,149	49,175
2014	55,040	60,165	67,421	76,708	97,173	51,322	51,321
2015	56,962	62,680	70,749	80,976	103,107	52,831	52,820
2016	58,321	64,642	73,564	84,780	108,654	53,790	53,778
Fishing Mort	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2003	0.051	0.051	0.051	0.051	0.051	0.051	0.051
2004	0.261	0.196	0.131	0.074	0.000	0.324	0.261
2005	0.250	0.196	0.131	0.074	0.000	0.295	0.250
2006	0.210	0.172	0.126	0.074	0.000	0.241	0.260
2007	0.189	0.157	0.117	0.074	0.000	0.215	0.226
2008	0.180	0.150	0.113	0.074	0.000	0.204	0.211
2009	0.178	0.148	0.112	0.074	0.000	0.203	0.207
2010	0.186	0.154	0.115	0.074	0.000	0.214	0.216
2011	0.200	0.163	0.120	0.074	0.000	0.231	0.232
2012	0.212	0.171	0.123	0.074	0.000	0.248	0.248
2013	0.222	0.177	0.125	0.074	0.000	0.261	0.261
2014	0.229	0.181	0.127	0.074	0.000	0.270	0.270
2015	0.234	0.184	0.128	0.074	0.000	0.276	0.276
2016	0.238	0.187	0.129	0.074	0.000	0.280	0.280
Yield	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2003	3,500	3,500	3,500	3,500	3,500	3,500	3,500
2004	15,684	12,036	8,211	4,744	0	19,013	15,684
2005	12,336	10,305	7,355	4,421	0	13,748	12,336
2006	8,945	7,982	6,465	4,178	0	9,508	10,898
2007	7,341	6,728	5,658	4,002	0	7,669	8,403
2008	6,596	6,097	5,219	3,887	0	6,877	7,296
2009	6,462	5,954	5,113	3,860	0	6,783	7,031
2010	7,011	6,374	5,399	3,955	0	7,456	7,605
2011	8,029	7,164	5,902	4,152	0	8,659	8,742
2012	9,114	8,002	6,431	4,401	0	9,929	9,969
2013	10,074	8,764	6,942	4,680	0	11,022	11,038
2014	10,856	9,426	7,420	4,966	0	11,863	11,866
2015	11,457	9,967	7,841	5,241	0	12,479	12,477
2016	11,897	10,398	8,210	5,496	0	12,881	12,878

Table 5.8. Estimated total Greenland turbot harvest by area, 1977-2002.

Year	EBS	Aleutians	Year	EBS	Aleutians
1977	27,708	2,453	1991	3,781	4,397
1978	37,423	4,766	1992	1,767	2,462
1979	34,998	6,411	1993	4,878	6,330
1980	48,856	3,697	1994	3,875	7,141
1981	52,921	4,400	1995	4,499	5,855
1982	45,805	6,317	1996	4,258	4,844
1983	43,443	4,115	1997	5,730	6,435
1984	21,317	1,803	1998	7,839	8,329
1985	14,698	33	1999	5,179	5,391
1986	7,710	2,154	2000	5,667	5,888
1987	6,519	3,066	2001	4,102	4,252
1988	6,064	1,044	2002	3,011	3,153
1989	4,061	4,761			
1990	7,702	2,494			

Table 5.9. Summary management values based on this assessment. Note that the fishing mortality rates assume 50% contribution from longline gear and 50% from trawl.

Management Parameter	Value
M	0.18 yr-1
Amendment 56 Tier (in 2002)	3a
Approximate age at full recruitment	10 years
$F_{35\%}$ (F_{OFL})	0.32
$F_{40\%}$	0.26
$B_{100\%}$	147,000 t
$B_{40\%}$	58,800 t
$B_{35\%}$	51,500 t
Year 2004 female spawning biomass	69,300 t
Year 2004 total (age 1+) biomass	132,000 t
$F_{ABC} = F_{40\%}$ (max permissible)	0.26
Maximum permissible ABC	15,700
F_{ABC} = 5-year average	0.07
Recommended ABC	**4,740**
$F_{overfishing} = F_{35\%}$	0.32
Overfishing level	**19,300 t**

Figures

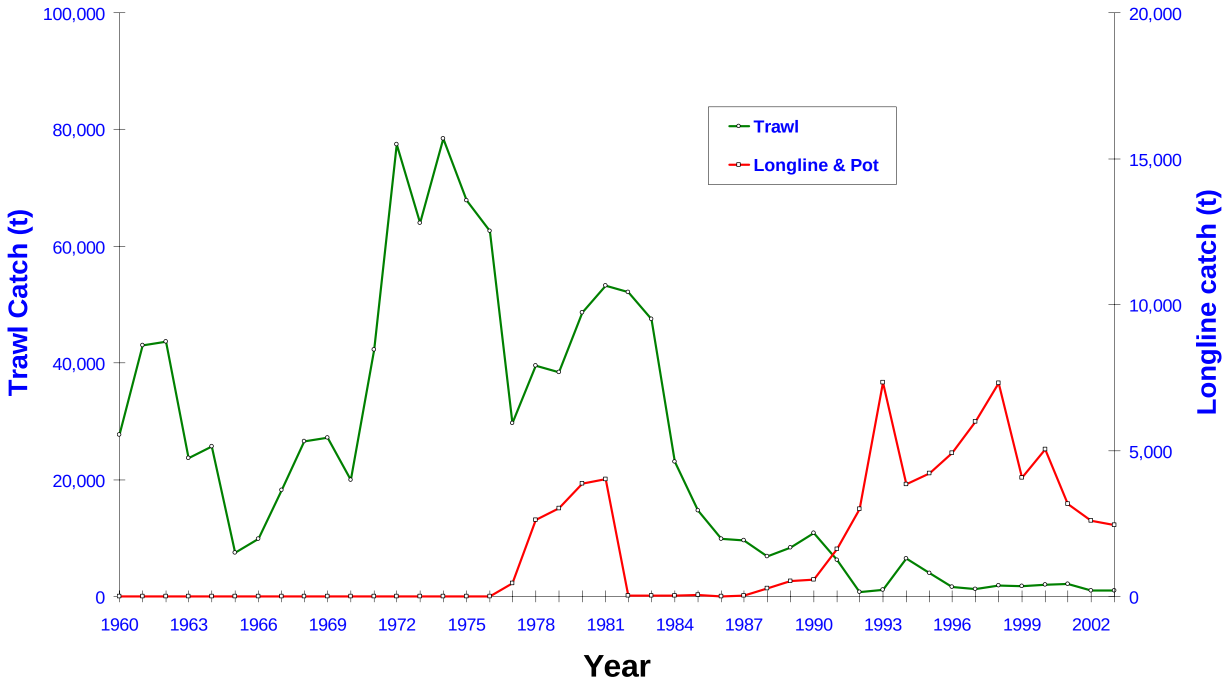

Figure 5.1. Comparison of trawl (1960-2003) and longline (1977-2003) catches of Greenland turbot in the combined EBS/AI area.

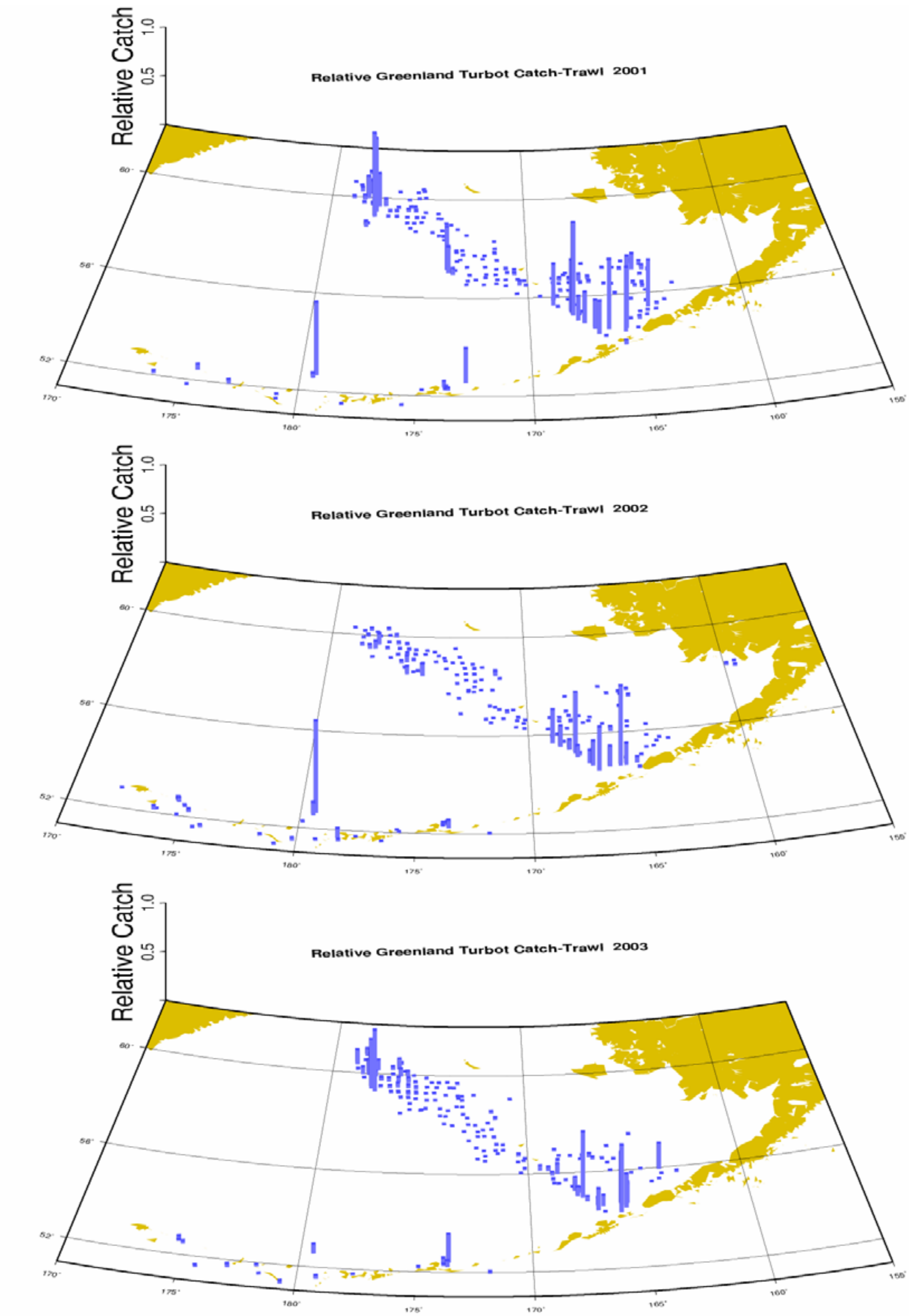

Figure 5.2. Distribution of Greenland turbot catch by trawl vessels based on aggregated NMFS observer data, 2001-2003. Vertical lines represent the relative magnitude of Greenland turbot catch for each 30’ longitude by 15’ latitude grids.

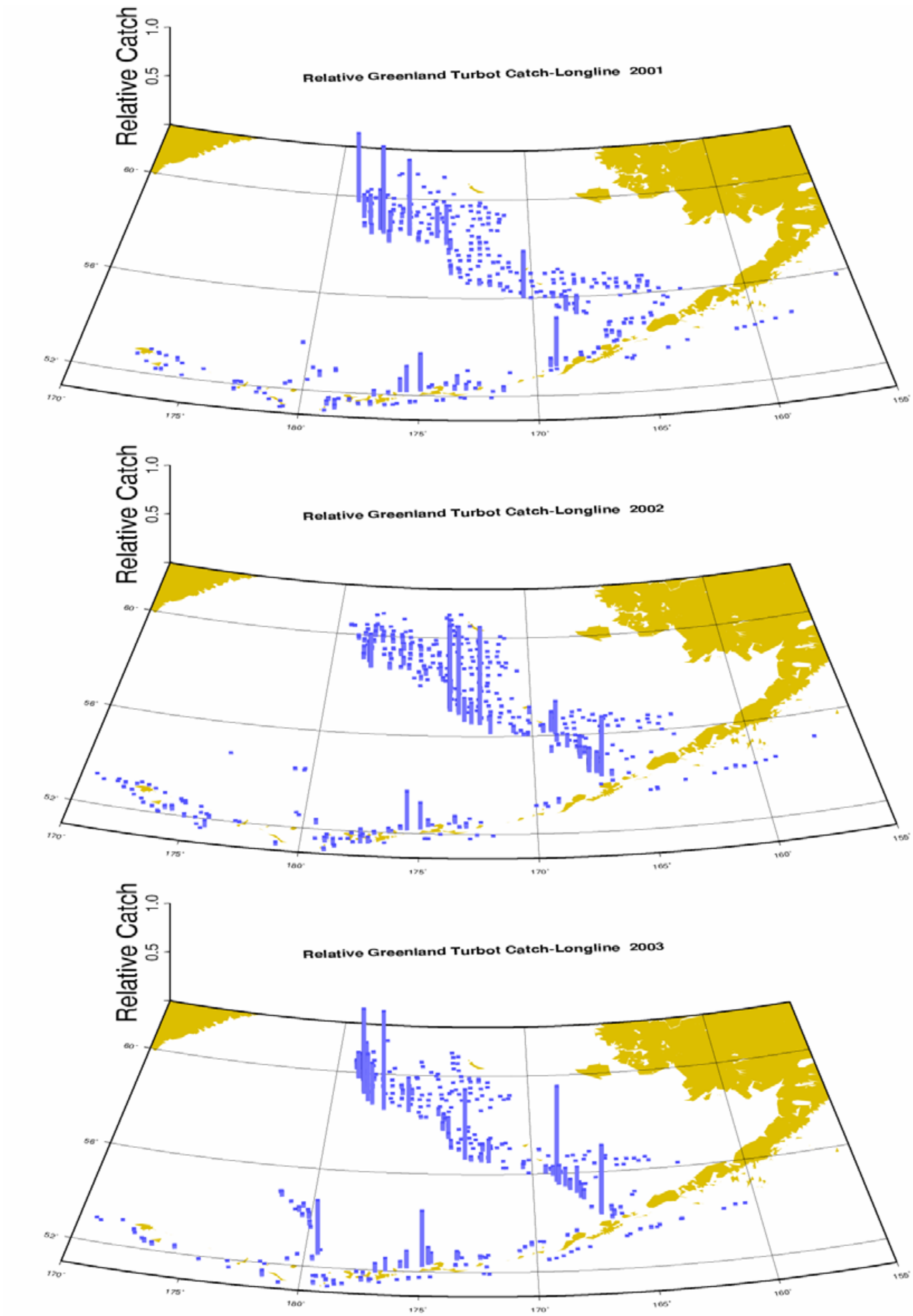

Figure 5.3. Distribution of Greenland turbot catch by longline vessels based on aggregated NMFS observer data, 2001-2003. Vertical lines represent the relative magnitude of Greenland turbot catch for each 30' longitude by 15' latitude grids.

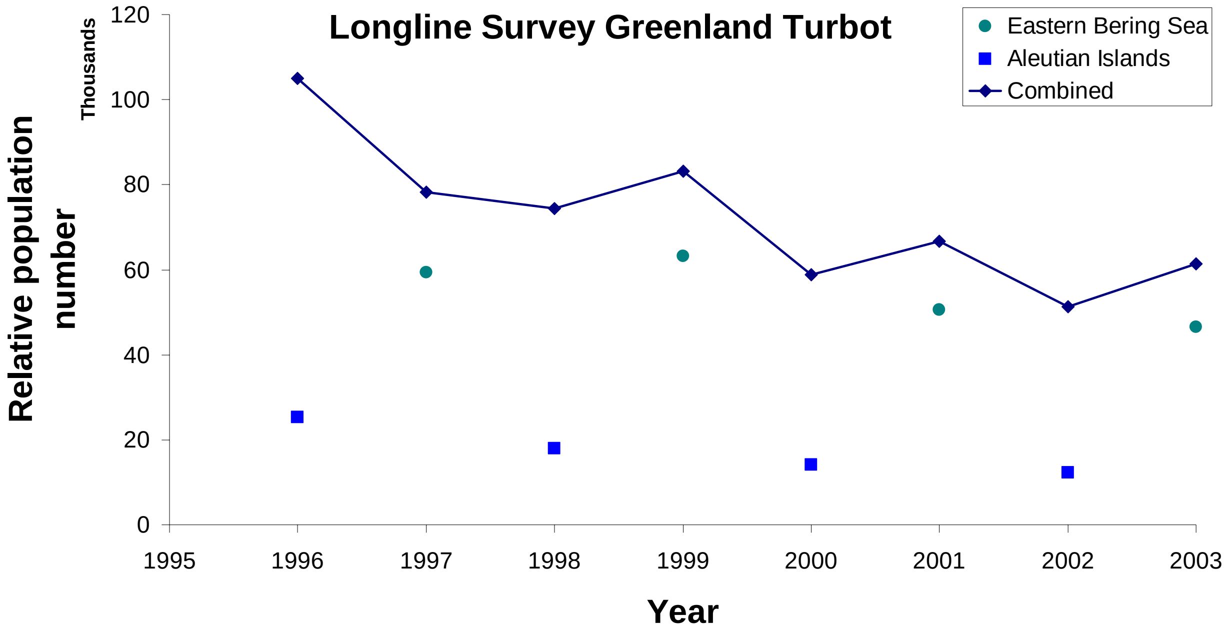

Figure 5.4. Greenland turbot longline survey abundance trends for the 2 regions and as combined and used within the assessment model.

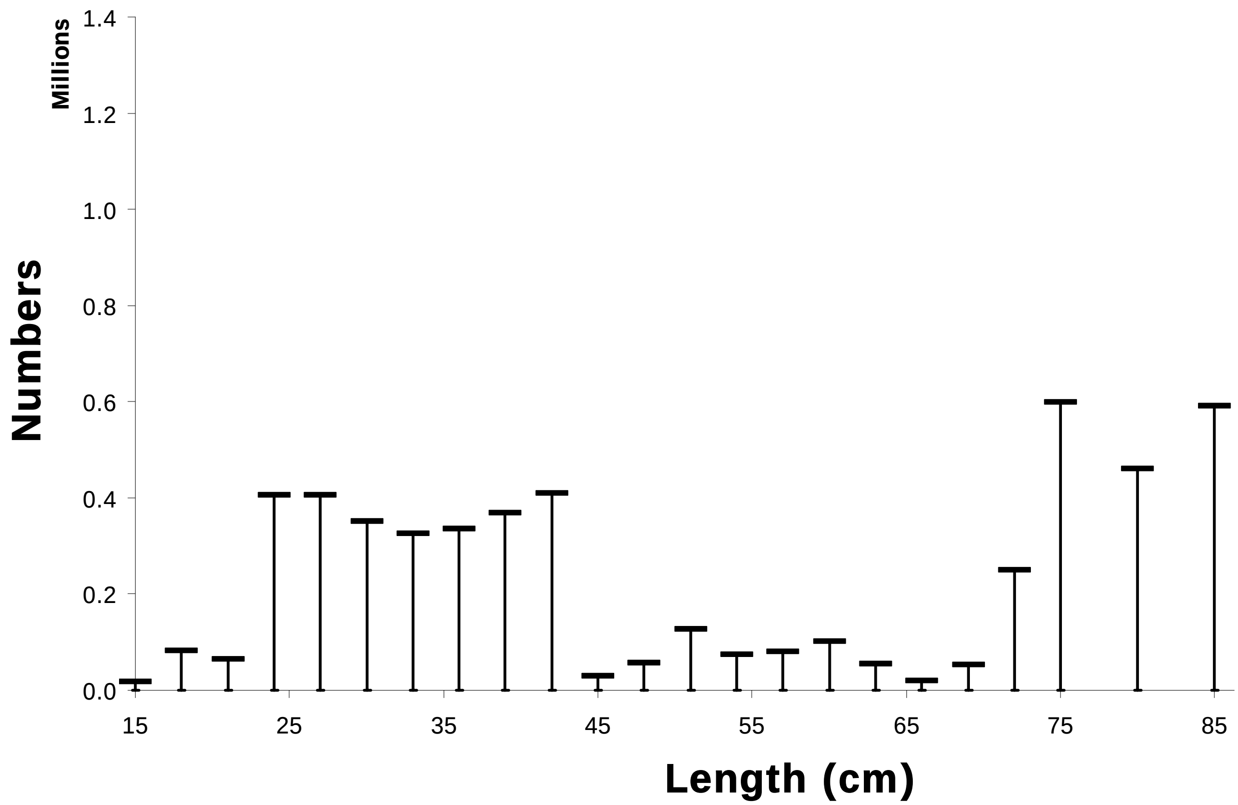

Figure 5.5. Length frequency of Greenland turbot observed from the summer 2003 NMFS bottom trawl **shelf** survey.

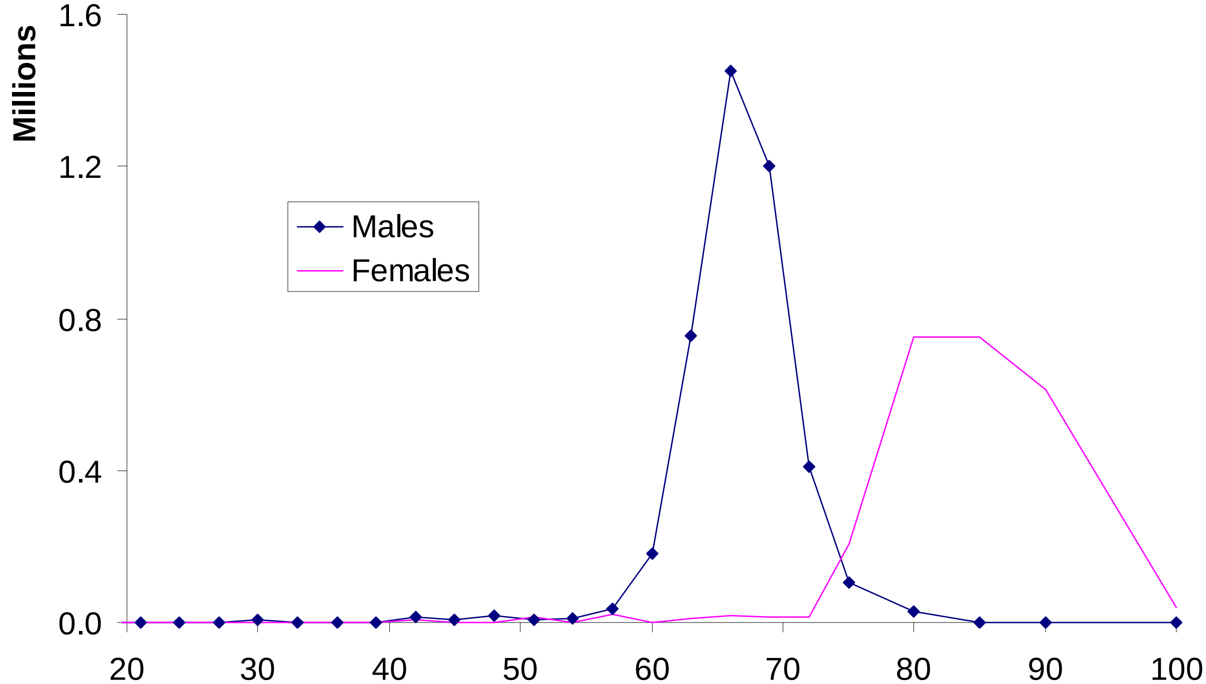

Figure 5.6. Length frequency of Greenland turbot observed from the summer 2002 NMFS bottom trawl **slope** survey.

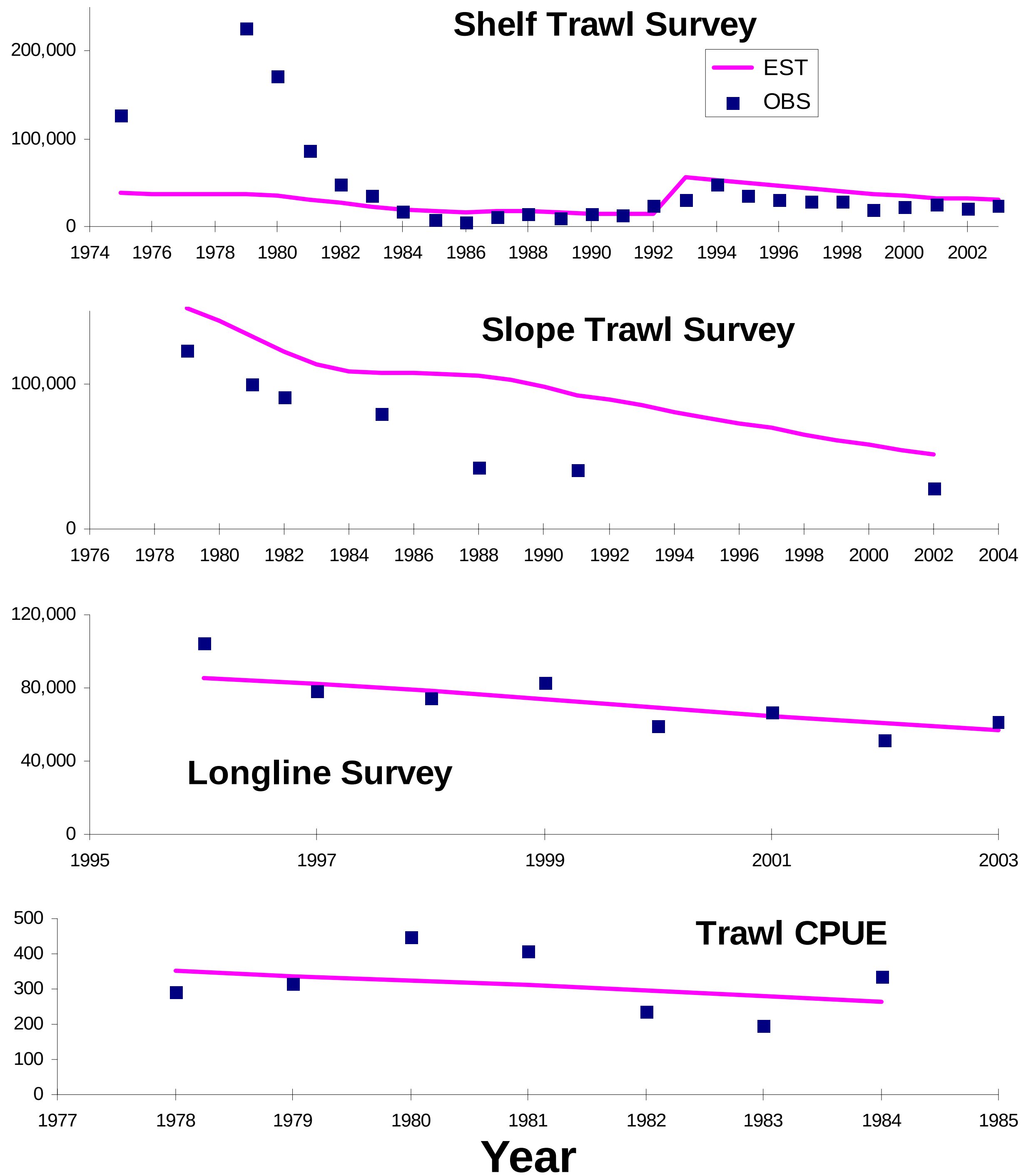

Figure 5.7. Fits to the different survey and fishery indices for Greenland turbot in the EBS/AI region.

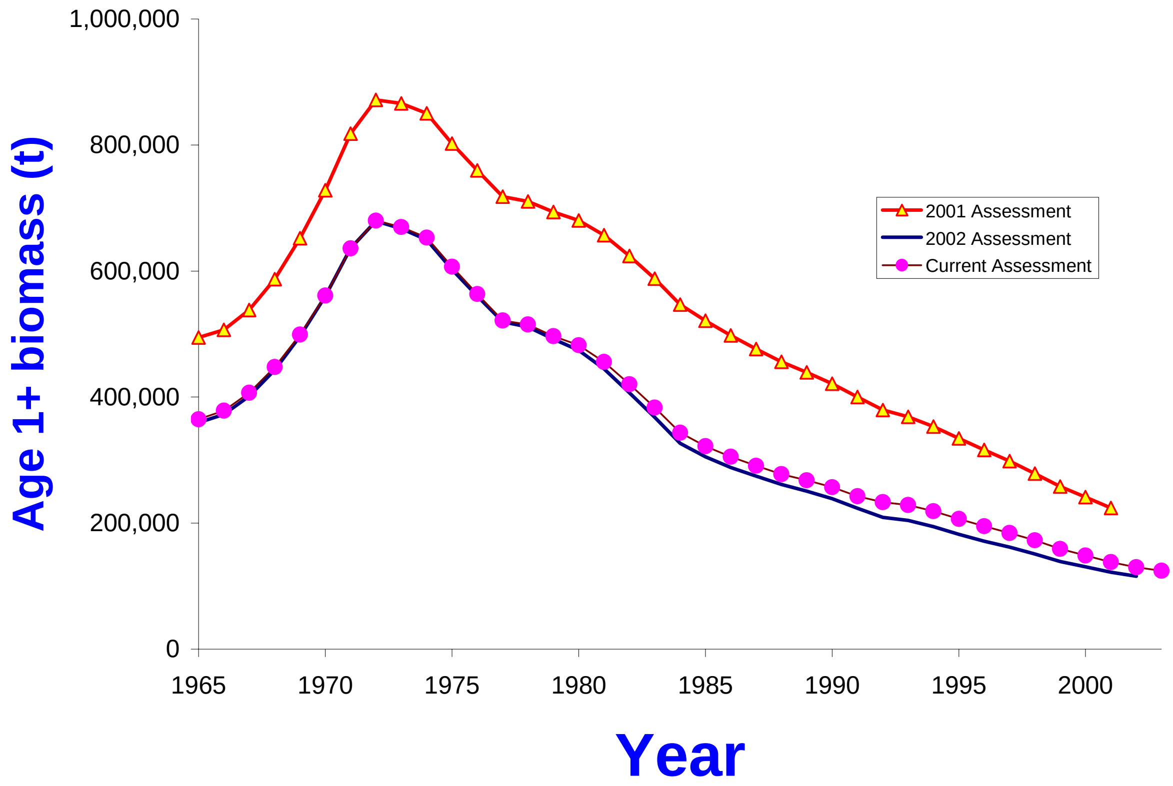

Figure 5.8 Total age 1+ biomass trend for Greenland turbot in the EBS/AI region, 1965-2003 compared previous assessments (Ianelli et al. 2002).

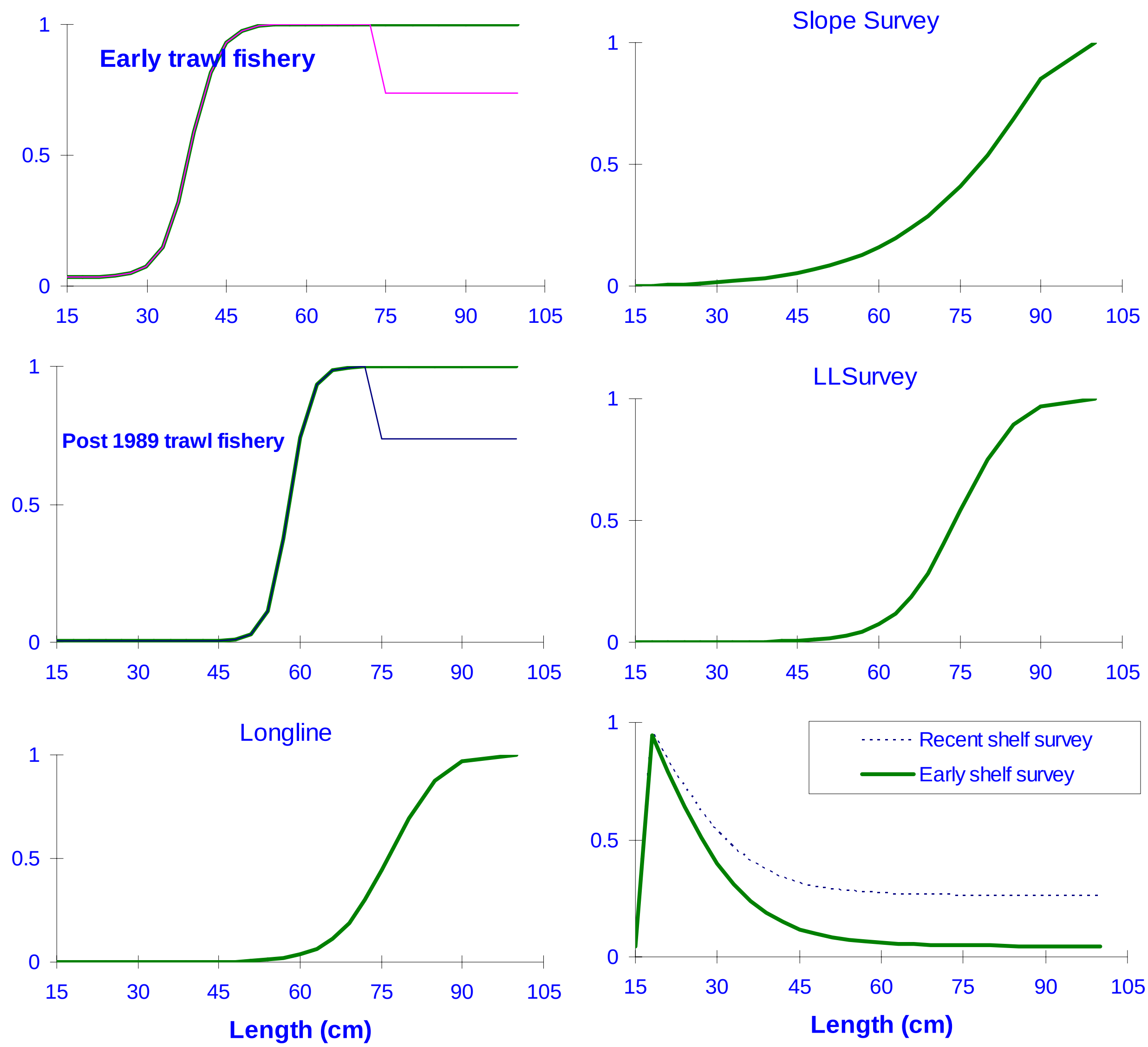

Figure 5.9. Size-specific selectivity patterns for surveys and fisheries of Greenland turbot in the EBS/AI region. Thin lines represent differential selectivity of males.

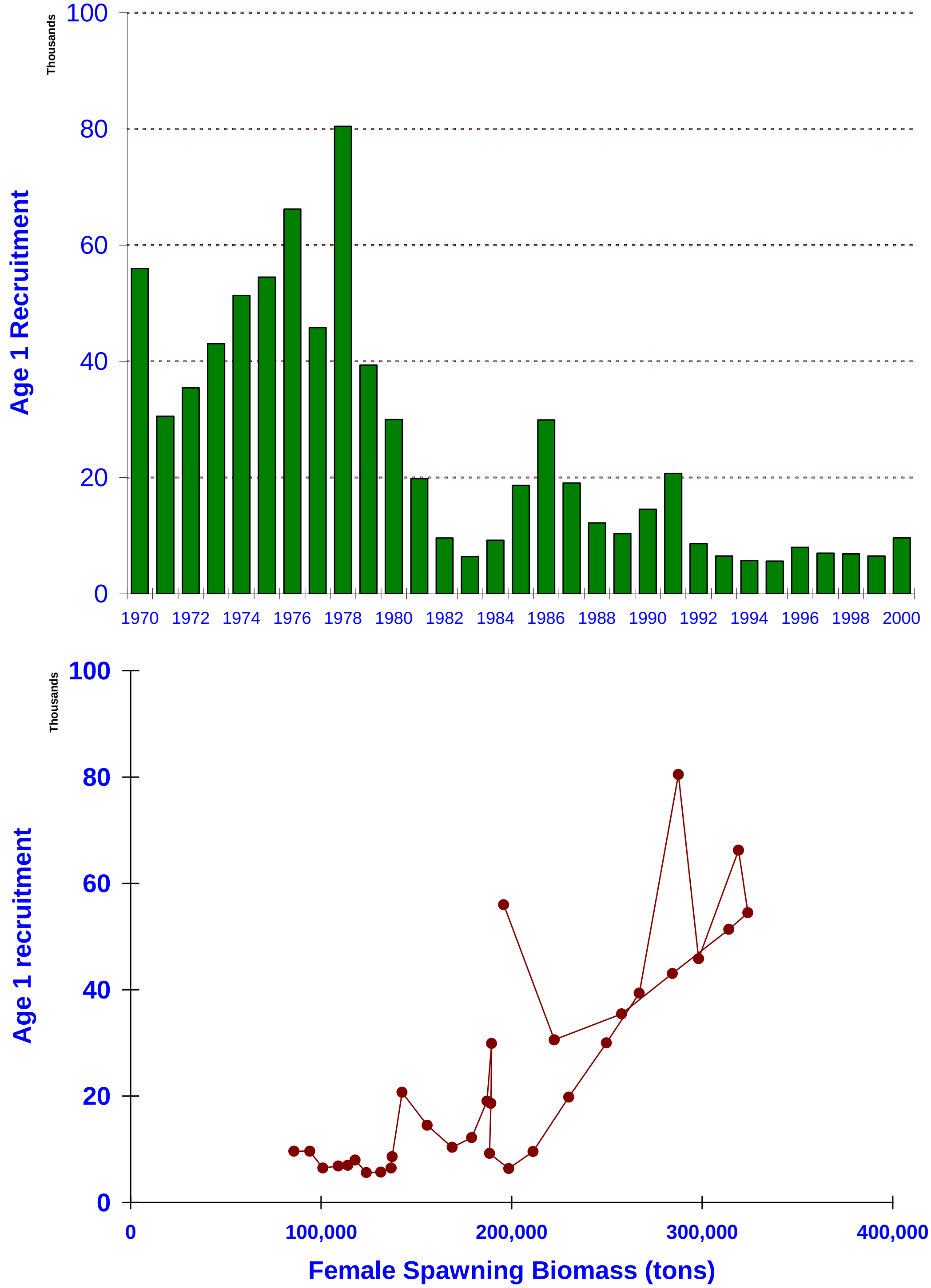

Figure 5.10. Estimated recruitment to age 1 (upper panel) and the observed stock-recruitment pattern (lower panel) of Greenland turbot in the EBS/AI region, 1970-2003.

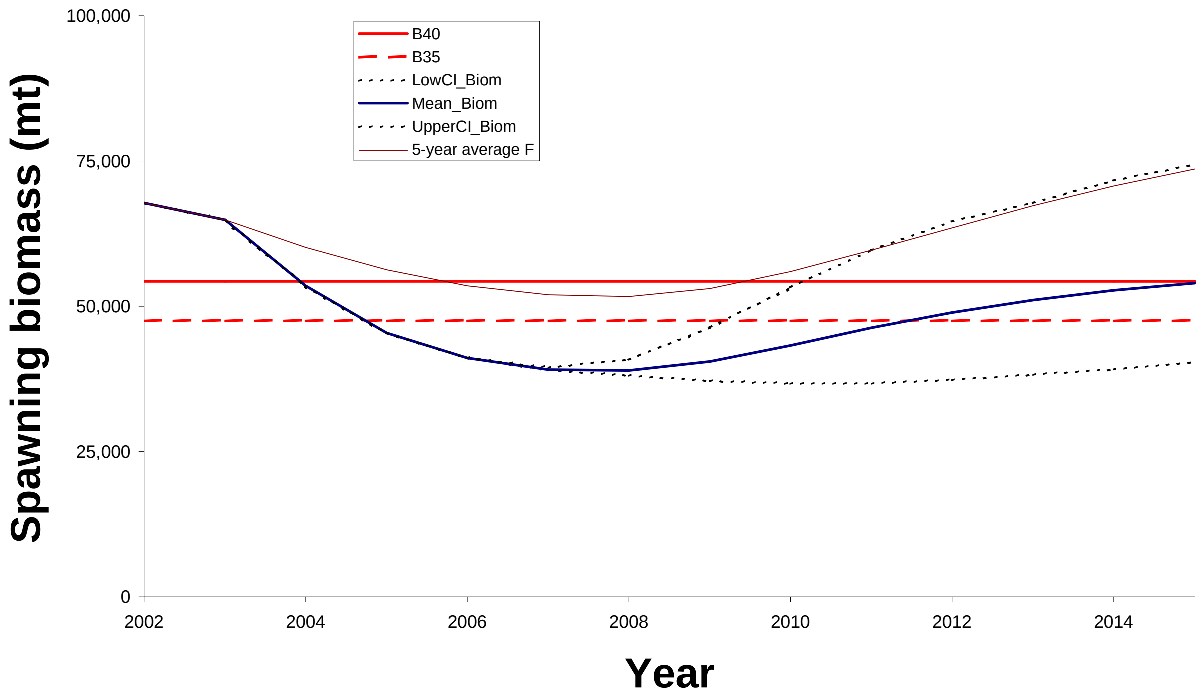

Figure 5.11. Stochastic trajectory of Greenland turbot female spawning biomass and projected levels for the maximum allowable fishing mortality rate under Amendment 56/56, Tier 3 and showing the mean expected value fishing under a constant *F* based on the recent 5-year average. These runs assume (conservatively) that the relative fishing mortality rates between longline and trawl fishing gear are equal. The dotted lines represent the upper and lower 90% confidence limits.